INFLUENCE OF ROCKET ENGINE CHARACTERISTICS ON SHAFT SEAL TECHNOLOGY NEEDS

John E. Keba
Rocketdyne Division
Boeing North American, Inc.
Canoga Park, California

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John E. Keba
Rotating Machinery Analysis Group
Rocketdyne Division
Boeing North American, Inc.

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Follow-on to last years presentation on "Rocket Turbomachinery Shaft Seals" which described the sealing technology challenges of Inter-Propellant Seal Systems and Lift-Off Seal Systems.

This presentation will highlight how the type of engine and mission influence shaft seal requirements.

The intent is to explain that rocket engine seal technology development plans need to focus not only on a particular type of seal system (IPS or Lift-Off), but they also need to be focused on a particular engine and mission type (application) as well. New engines need seal development programs.

Influence of Rocket Engine Characteristics on Shaft Seal Technology Needs

- **Introduction -- Rocket Turbomachinery Shaft Seals**
  - **Inter-Propellant-Seal (IPS) Systems**
  - **'Lift-off' Seal Systems**
  - **Technology Development Needs**
- **Rocket Engine Characteristics**
  - **Engine cycles, propellants, missions, etc.**
  - **Influence on shaft sealing requirements**
- **Conclusions**

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Introduction is quick review of IPS seals using SSME HPOTP seal as example, and Lift-off seals using SSME HPFTP lift-off seal as example. Areas where technology advancement is desirable are highlighted.

Rocket engines will then be be discussed, emphasizing how different characteristics - cycle type, propellant, mission etc -- drive seal requirements. Major point is there is much more diversity in the design of rocket turbopump seal systems than is generally appreciated.

Conclusion is that new propulsion systems for launch vehicles inevitably place new demands on shaft seal systems that are not adequately met with existing seal technology.

Inter-Propellant-Seal (IPS)

- IPS Purpose
  - Separate incompatible fluids
  - Limit propellant leakage

- Technology advancement needs
  - Reduction or elimination of buffer gas consumption
  - Reduce or eliminate drain requirements
  - Reduce length of seal system
  - Higher seal surface velocities

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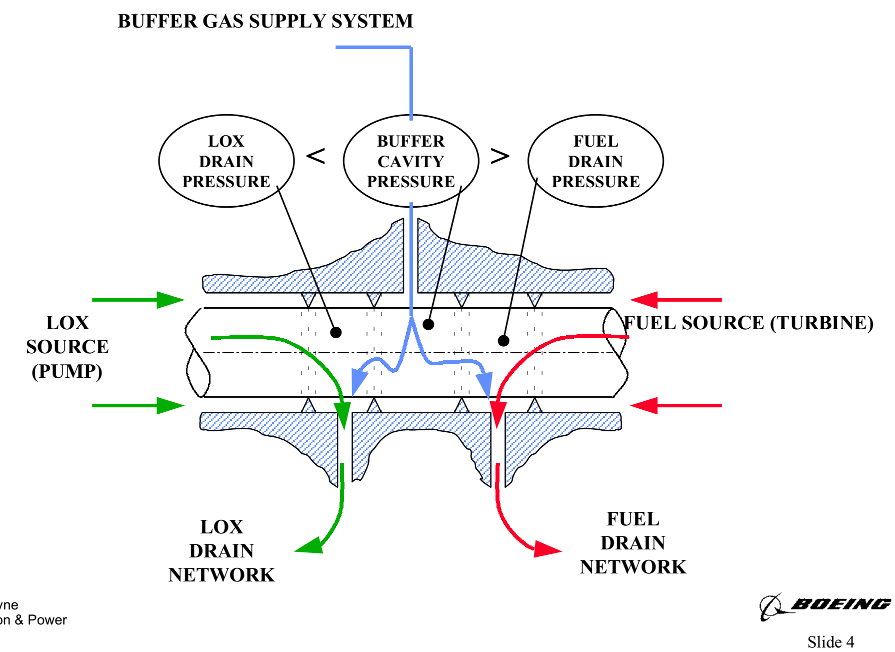
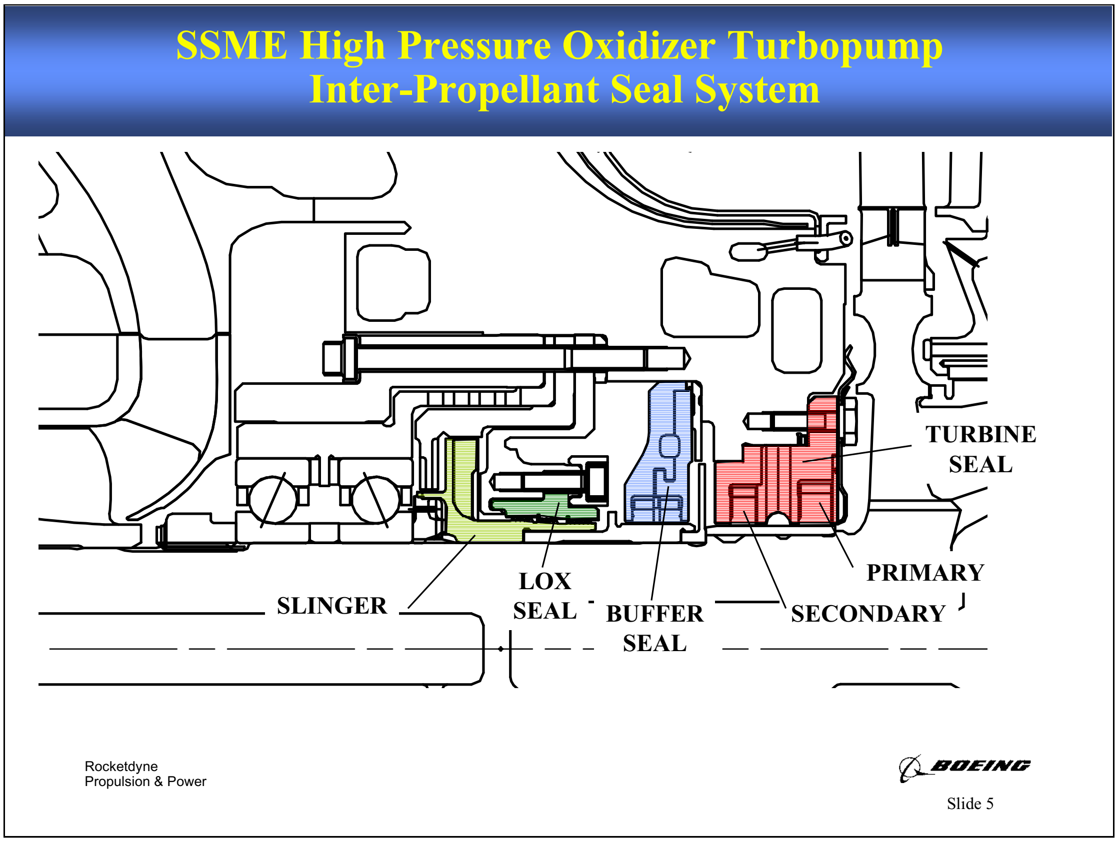
The fundamental purpose of the IPS is to keep the oxidizer and the fuel separate inside the turbopump. If they should mix inside the pump, it is likely that they will ignite causing a catastrophic failure of the engine. These seals are typically used between the pump and turbine in oxidizer turbopumps and, in single shaft turbopumps (pumps where both fuel and oxidizer are mounted on one shaft) between the fuel pump and oxidizer pump.

Inter-Propellant Seal System



Schematic of a typical inter-propellant seal. There are generally at least three discrete seal components. An inert gas, helium, is used to provide a buffer zone between the two incompatible fluids. There are five subsystems in addition to the seals themselves which require equal attention in design -- the two sources, the two drains and the buffer gas supply. The basic operating requirement is the buffer cavity pressure is always maintained higher than either of the adjacent drain pressures.



Detail of the HPOTP inter-propellant seal package.

All seal are clearance type seals. LOX seal leakage is high during chill and at low power settings when the slinger does not vaporize the fluid. Turbine seal ΔP is about 3000 psi -- to high for many seal designs.

Very robust system but significant performance, size and weight penalty for low thrust engines.

Lift-off Seal System

- Purpose
  - Prevent propellant leakage into turbine before start and after cut-off
  - Limit leakage into turbine during operation
- Technology advancement needs
  - Reduction in seal system length (all-in-one seal)
  - Elimination of overboard drain/vent line
  - Lower operating leakage

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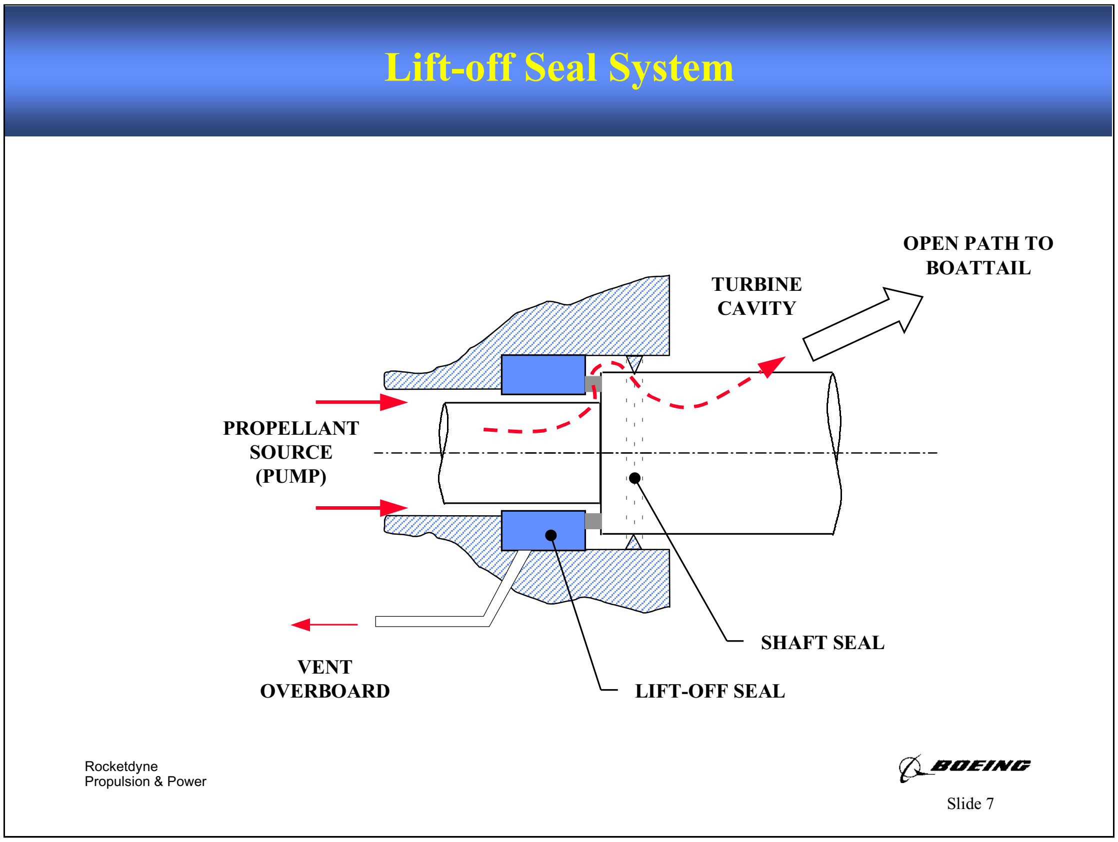
Lift-off seal: Rocketdyne's terminology for a shaft seal (generally face seal) which provides a contacting, very low leakage seal at zero or slow speed operation and opens fully during operation, providing negligible flow restriction.

A separate seal, typically a clearance type seal, is used in series with the lift-off seal to limit leakage during operation.

Long, complicated seal system. High speed capability face seals may provide significant improvement in some applications.

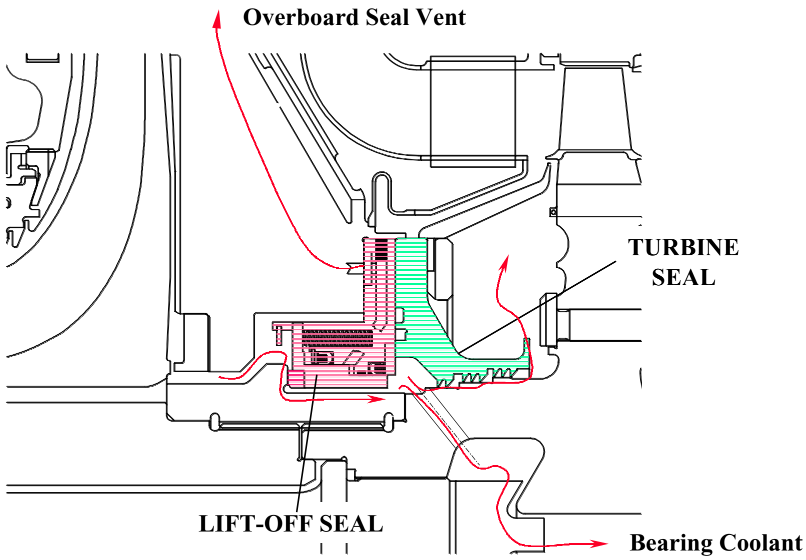


Schematic of lift-off seal. Leakage into turbine cavity has open path to nozzle. Problem with hydrogen during chill because difficult to dilute to safe concentration. Thermal condition of turbine also undesirable with cryogenic leakage. With storable fuels, leakage into turbine can also present problems.

Seal actuates open when rising pressure on upstream and/or downstream side cause pressure loading to overcome spring load. An overboard vent is usually necessary to provide low pressure on the back side of the carbon so that the seal stays open without a pressure drop across the nose.

Shaft seal provides the resistance to leakage after the lift-off seal opens, limiting propellant flow into the turbine.

SSME HPFTP Lift-off Seal System



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SSME High Pressure Fuel Turbopump Lift-off seal and turbine shaft seal.

Lift-off seal prevents liquid hydrogen leakage into turbine during pump chilldown. During operation, Lift-off seal opens and leakage into turbine is limited by stepped labyrinth seal. Hole in shaft between Lift-off seal and labyrinth seal provides coolant flow to turbine end bearing.

Engine Characteristics

Rocket Engine Classifications

Engine Cycle

'Open' Cycle
- Gas Generator
- Expander

'Closed' Cycle
- Staged Combustion
  - Fuel Rich
  - LOX Rich
- Expander

Vehicle
- Booster
- Upper Stage
- Single Stage-to-Orbit

Propellants

Cryogenic
- LOX -- LH2
- LOX -- Kerosene

Storable
- NTO -- MMH, UDMH, etc..
- H2O2 -- Kerosene

Other

Expendable Vs. Reusable

Man Rated Vs Non-Man Rated

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Rocket engines can be classified in various ways -- by their thermodynamic cycle, by propellant combination, vehicle type or application and others. These engine characteristics combine into a large number of permutations and result in unique turbomachinery requirements for every application. Consequently, shaft seal systems generally have unique requirements for each engine.

Engine Cycle

Cycle defined by fluid source used to drive turbines

'Open' Cycle -- Turbine drive gas exhausted downstream of Main Combustion Chamber (MCC)

- Gas Generator Cycle -- Propellants burned (fuel rich) to drive turbine
- Expander Cycle -- Propellant is vaporized and heated by MCC or nozzle to drive turbine

Influence on shaft seals:

- Relatively low turbine cavity pressures
- Impulse turbine -- turbine flows affected by seal leakage

'Closed' Cycle

- Staged Combustion - Partial combustion of propellants, turbine exhausts into MCC injector head

Influence on shaft seals:

- Very high pressure in turbine cavity
- Relatively high turbine flow rate compared to seal leakage
- Very high pump pressures

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The cycle type most directly affects seal operating pressures and allowable leakage into or from the turbine cavity. This may determine the type of seal required -- clearance seals for high pressures or rubbing contact seals for minimum leakage.

Vehicle

- Booster
  - High thrust -- high propellant flowrates, large pumps
  - Weight and performance less critical than upperstage and STO
- Upper Stage
  - Low thrust -- low flowrates, small higher speed pumps
  - Restart requirement
  - Weight and performance critical
- STO
  - Wide throttle range, large pumps
  - Weight and performance very critical

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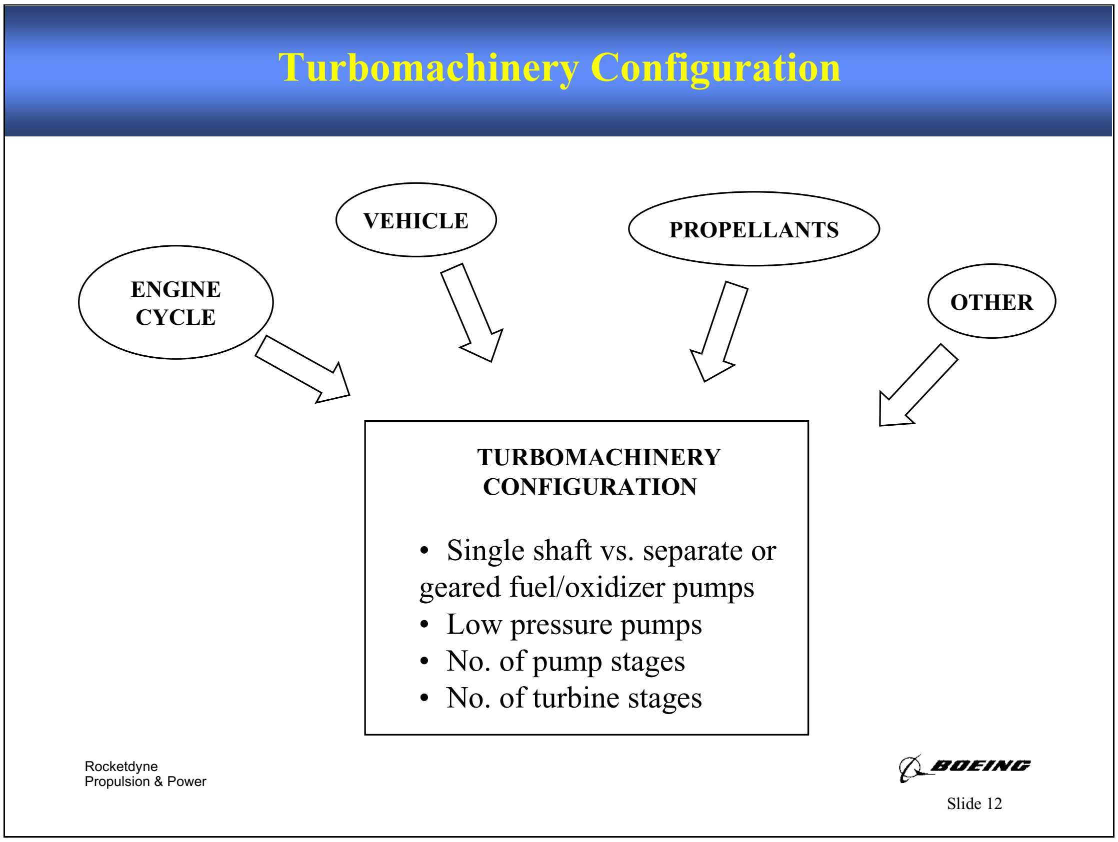
The vehicle or application generally defines the thrust class and performance level required. Boosters are generally large and shaft leakages are generally more of a safety and operability concern than a performance concern. Often, multiple engines are used for a booster stage. Overall engine performance is not as critical because the propulsion system is not carried to full orbital velocity.

Weight is more critical for the upperstage because it trades almost one-to-one with payload weight. Therefore the importance of seal system performance increases relative to that of other trade factors.

STO combines the requirements of booster and upper stage, often adding the additional requirement of reusability.



Turbomachinery Configuration covers the number of turbopumps and the basic layout of the individual turbopumps -- whether pump inducers are needed, type of turbine, number of pump and turbine stages, approximate size and speed. The engine characteristics in conjunction with constraints on turbopump component capabilities set the turbomachinery configuration.

As examples:

- Differences in fuel density compared to oxidizer density generally determines if individual pumps are required.
- Propellant supply conditions(vehicle tanks) influence the need for separate low pressure pumps and effect turbopump speed selection.
- Propellants influence materials selection which impact component capabilities.
- Safety factors and life requirements are set by the application and impact component capabilities.

With the basic turbomachinery configuration set, seal system requirements are determined in concert with bearing design and rotordyamic analysis.

Engine Data Summary

Engine Cycle	Propellants	Engine Designation	Vehicle	Thrust	Turbomachinery Configuration
Gas Generator	LOX - RP1	F1	Booster - Saturn 5	1,500,000 SL	Single Shaft
	LOX - RP1	RS-27	Booster - Delta	200,000 SL	Geared
	LOX - LH2	Vulcain	Booster - Ariane 5	225,000 SL	Two Shaft
	LOX - LH2	HM7	Upper Stage - Ariane 4	14,000	Geared
	NTO - UH25	Viking	Booster - Ariane 4	150,000 SL	Single Shaft
	NTO - A50	LR-87	Booster - Titan	275,000 Vac	Geared
	NTO - A50	LR-91	Upper Stage - Titan	100,000 Vac	Geared
Expander	LOX - LH2	RL-10	Upper Stage - various	25,000 Vac	Geared
	LOX - LH2	LE-5	Upper Stage - H2	27,000 Vac	Two Shaft
Staged Combustion - Fuel Rich	LOX - LH2	SSME	Booster - Space Shuttle	375,000 SL	2 HP and 2 LP
	LOX - LH2	LE-7	Booster - H2	190,000 SL	Two Shafts
	LOX - LH2	RD-0120	Booster - Energia	400,000 SL	Single Shaft and 2 LP
Staged Combustion - Oxidizer Rich	LOX - RP1	RD-170	Booster - Zenit	1,600,000 SL	Single Shaft and 2 LP
	LOX - RP1	RD-120	Upper Stage - Zenit	187,000 Vac	Single Shaft and 2 LP
	NTO - UDMH	RD-253	Booster - Proton	330,000 SL	Single Shaft

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Current and past engine systems span a wide range of cycles, propellants, applications and turbopump configurations. Possible new vehicles such as RLV (Reusable Launch Vehicle), LFBB (Liquid Flyback Booster), SMV (Space Maneuver Vehicle) and commercial boosters and upper stages will expand the range of configurations further. Each presents a unique combinations of shaft sealing requirements for which existing experience is inadequate.

Influence of Rocket Engine Characteristics on Shaft Seal Technology Needs

- **Conclusion -- New propulsion systems for launch vehicles inevitably place new demands on shaft seal systems that are not adequately met with existing seal technology.**

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Seal requirements vary greatly with the the engine application. Future engine needs must be considered in formulating seal component development plans for rocket engine use. Just as important, new engine programs must consider shaft seal needs in their technology development plans.